

**VIBRATION ANALYSIS OF A BEAM STRUCTURE ATTACHED WITH
TWO DYNAMIC VIBRATION ABSORBERS**

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**A THESIS SUBMITTED AS FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF
MASTER OF MECHANICAL ENGINEERING**

**FACULTY OF MECHANICAL AND MANUFACTURING ENGINEERING
UNIVERSITI TUN HUSSEIN ONN MALAYSIA**

SEPTEMBER, 2014

*Dedicated specially to my parents
Jaini Bin Mahli & Zainab Balitang,
My beloved husband and family
All those who have been a great help in the completion of this thesis
My love to all of you will remain forever...*



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ACKNOWLEDGEMENT

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

In the name of Allah, the Most Gracious, the Most Merciful

All the Praises and Thank to Allah and may peace be upon to Prophet Muhammad S.A.W, the messenger of Allah. With blessing and generosity from Allah, I have the strength to complete this research successfully. I would like to express my most sincere gratitude to my supervisor, Dr Muhd Hafeez bin Zainulabidin who provided considerable invaluable insights, guidance and advices also who always help me enhance the quality of my work. His intelligence and determination has been a source of inspiration and their demands for quality and perfection give me a challenge in order to accomplish my project. Without his patient support and enlighten guidance, it is impossible for me to complete this long journey. Thanks for all of the efforts and precious time for my research.

Special thanks dedicated to laboratory staff, Mr Md Zainorin Kasron from Noise & Vibration Laboratory for his willingness assisting me and sharing his idea on implementation of my project. Also thanks to all my dearest friends for all their supports. Especially to Nor Akmal Md Noar, your helpful and support during the completion of the research is most appreciates. The friendship, collegiality and support provided will not be forgotten.

Finally, I dedicate this thesis to my beloved family specially, a greatest appreciation thanks to my parents, Jaini bin Mahli & Zainab Balitang for their encouragement, guidance, never give up sending me a prayers and endless support.

ABSTRACT

A fixed end beam is a structural element supported at both sides which carries load primarily in flexure that may experience vibration as it does carry vertical loads and gravitational forces. Its exposure to vibration can lead to excessive deflections and failure of to the structure. The aim of this research is to develop the application of dynamic vibration absorber on a fixed end beam structure. A classical mathematical model based on dynamic vibration absorber theory is improved by an analytical derivation until two degree of freedoms. The theoretical model is verified by experimental works. In experimental, two vibration absorbers was fabricated to be installed to the beam in four different conditions; and subjected to a force vibration frequency loading using an exciter. The resonance frequencies of interest were 11.23Hz and 35.45Hz. The vibration level that occurred on the beam is measured by comparing the effect of absorber presence to see the reduction in its amplitudes. Based on the experimental and theoretical analysis, both shows reduction in the beam amplitudes. From those results can be concluded that the dynamic vibration absorber has an ability to reduce and suppresses the beam vibration whereas the third condition has been chosen as the best arrangement where the persistent reduction results recorded 95 and 99 percents reduction of first and second DVA respectively. The knowledge gained from this research can be used to minimize the vibration amplitude of a structures and machines, increasing their life-span simultaneously. The other benefit comes from this research in specific or potential application aspect is it could control vibration in building or bridge structure and airplane wing flutter control.

ABSTRAK

Rasuk tetap merupakan satu struktur yang disokong pada kedua-dua hujung yang mungkin menanggung beban lenturan akibat getaran yang berpunca daripada beban menegak dan daya graviti. Pendedahan rasuk ini kepada getaran dalam satu jangka masa yang lama akan menyebabkan berlakunya lenturan yang berlebihan yang boleh mengakibatkan kegagalan pada strukturnya. Tujuan utama kajian ini dijalankan adalah untuk membangunkan aplikasi penyerap getaran dinamik pada struktur rasuk tetap. Model matematik klasik berdasarkan teori penyerap getaran dinamik ditambahbaik dengan satu terbitan analisis sehingga dua darjah kebebasan. Model teori ditentusahkan melalui ujikaji eksperimen. Untuk eksperimen, dua penyerap getaran telah difabrikasi untuk dipasang kepada rasuk dalam empat keadaan yang berbeza dan dikenakan beban getaran yang berlainan frekuensi dengan menggunakan penggetar. Frekuensi resonan yang menjadi tumpuan kajian adalah pada 11.23Hz dan 35.45Hz. Tahap getaran yang terhasil pada rasuk tetap diukur dengan membandingkan kesan kehadiran penyerap getaran untuk melihat pengurangan dalam amplitudnya. Data yang diperolehi menunjukkan terdapat pengurangan pada nilai amplitud rasuk bagi kedua-dua kaedah. Hasil daripada keputusan itu dapat disimpulkan bahawa penyerap getaran dinamik mempunyai keupayaan untuk mengurangkan dan menyekat getaran di mana penyerap getaran yang diletakkan dalam keadaan ketiga dipilih sebagai yang terbaik antara semua keadaan di mana pengurangan amplitud sebanyak 95 dan 99 peratus dicatat oleh penyerap getaran pada mod pertama dan kedua. Pengetahuan yang diperolehi daripada kajian ini boleh digunakan untuk meminimumkan amplitud getaran pada struktur dan mesin, sekaligus memanjangkan jangka hayatnya. Kelebihan lain daripada kajian ini secara spesifik atau dalam aspek potensi aplikasi adalah ia boleh diguna untuk mengawal getaran pada bangunan atau struktur jambatan dan juga sayap kapal terbang.

CONTENTS

TITLE	i
DECLARATION	ii
DEDICATION	iii
ACKNOWLEDGEMENT	iv
ABSTRACT	v
ABSTRAK	vi
CONTENTS	vii
LIST OF TABLES	xi
LIST OF FIGURES	xii
LIST OF SYMBOLS AND ABBREVIATIONS	xvi
LIST OF APPENDICES	xvii
 CHAPTER 1 INTRODUCTION	 1
1.1 Research background	2
1.2 Problem statement	4
1.3 Research aim	4
1.4 Objective (s) of the research	4
1.5 Scopes	5
1.6 Expected outcomes	6
1.7 Significant of research	7
 CHAPTER 2 LITERATURE STUDY	 8
2.1 Concept of vibration	8
2.2 Definitions and terminology	12
2.3 Beams	13
2.3.1 Fixed-ended beams	14

2.3.2	Fixed-fixed beam natural frequencies and mode shapes	15
2.3.3	Beams system having a concentrated mass	17
2.4	Vibration analysis	17
2.5	Dynamic vibration absorber	18
2.6	Previous researches	20
2.6.1	Dynamic vibration absorber as controllers	21
2.6.2	Structure tested	24
2.6.3	Experimental	27
2.7	Research flow chart	36

CHAPTER 3 THEORETICAL **37**

3.1	Introduction	37
3.2	Theoretical development	38

CHAPTER 4 EXPERIMENTAL **44**

4.1	Introduction	44
4.2	Beam structure set-up	45
4.3	Usefulness of the experimental	46
4.4	Instrumentation of the experiment	46
4.4.1	Speed control unit	46
4.4.2	IEPE (Integrated Electronic Piezoelectric) Sensors	47
4.4.3	DEWE-201	48
4.4.4	Shaker	48
4.5	Beam fabrication	49
4.5.1	Calculation getting the beam thickness	50
4.5.2	Beam stiffness calculation	52
4.5.3	Beam mass calculation	52
4.6	Beam clamps	53
4.7	Dynamic vibration absorber (DVA)	55
4.8	Equipment arrangement in experimental	56

4.9	Experimental works of DVAs	57
4.9.1	Beam response without DVAs	57
4.9.2	Beam response with DVAs	58
4.9.2.1	First condition	58
4.9.2.2	Second condition	59
4.9.2.3	Third condition	60
4.9.2.4	Fourth Condition	61
4.9.2.5	Procedures measuring the beam response for all conditions	61
4.10	Formula to convert amplitude (g) unit to amplitude (m)	62

CHAPTER 5 RESULT AND DISCUSSION **63**

5.1	Introduction	
5.2	Theoretical analysis	64
5.2.1	Determining fundamental frequency of the beam	64
5.2.2	Calculation obtaining tuneable mass dimension	70
5.2.3	Dynamic vibration absorber flyer's length	71
5.3	The derived theoretical formula	76
5.3.1	Amplitude of vibration of the main mass (X_m) with the motor speed (ω) at first mode	77
5.3.2	Absorber 1 displacements; X_1 for the first natural frequency	80
5.3.3	Amplitude of vibration of the main mass (X_m) with the motor speed (ω) at second mode	82
5.3.4	Absorber 2 displacements; X_2 for the second natural frequency	84

5.4	Experimental results	87
5.4.1	Comparison between experimental results	105
5.5	Overall results discussion	109
CHAPTER 6 CONCLUSION AND RECOMMENDATION		111
6.1	Conclusion	111
6.2	Recommendation for future works	113
REFERENCES		114
PUBLICATIONS		119
APPENDICES		120



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PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF TABLES

5.1	Fundamental frequency comparison between experimental and theory	71
5.2	Beam amplitudes of overall frequencies calculated using Using theoretical formula (first mode)	80
5.3	Amplitudes of absorber 1 (X_1) at overall frequencies	82
5.4	Beam amplitudes of overall frequencies calculated using theoretical formula (second mode)	85
5.5	Amplitudes of absorber 2 (X_2) at overall frequencies	87
5.6	Peak values of beam amplitudes and reduction percentage	110
5.7	Beam deflection results comparison of theoretical and experiment	114



PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF FIGURES

1.1	Amplitude-frequency response for system with and without tuned absorber	3
1.2	Expected amplitude-frequency response using DVA	6
2.1	Periodic simple harmonic	9
2.2	Undamped vibration	9
2.3	Damped vibration	9
2.4	Elements of vibratory system where: M-mass (stores kinetic energy); K-spring (stores potential energy, support load) and C-damper (dissipates energy, cannot support load)	10
2.5	Specification of vibration levels on a monograph	11
2.6	Harmonic motion; projection of rotating vector	13
2.7	A fixed-fixed suspension system	14
2.8	Grinder	15
2.9	Furnace	15
2.10	Modal shapes of fixed conditions at both ends	16
2.11	A clamped-clamped beam carrying a two degree-of freedom spring mass system	17
2.12	Input- output relationship of a vibratory system	18
2.13	Two DVAs	19
2.14	Dynamic vibration absorber manufactured	22
2.15	Neutralizers of dynamic stiffness attached to a structure which has M modes	24
2.16	Cantilever beam tested	25
2.17	A uniform beam with attached finite masses and spring	26
2.18	Structure with multiple neutralizers	27
2.19	(a) Beam like (b) force type (c) uncoupled force-moment neutralizer	27

2.20	(a) force only configuration (b) uncoupled force-moment Configuration	28
2.21	Base-excited SDOF system with 2DOF TVA	29
2.22	Schematic representation of the experimental set-up of the beam system including designed DVA	29
2.23	Beam with dynamic vibration absorber consisting of double-cantilever viscoelastic beam and spring-viscous damper	30
2.24	A pinned-pinned beam subjected to a concentrated force, P_c moving from the left-end to the right-end of the beam with a constant speed, V	31
2.25	(a) Translational	31
2.25	(b) Rotational	31
2.26	Schematic and deflection shape of a free-clamped beam under harmonic excitation distributed uniformly in the region $0 < x/L < 0.3L$...with only the translational dynamic absorber attached at $x/L=0.3$ -----with both translational and rotational dynamic absorber attached at $x/L=0.3$	31
2.27	Schematic and deflection shape of a clamped-clamped beam under harmonic excitation distributed uniformly in the region $x/L=0.2L$...with only the translational dynamic absorber attached at $x/L=0.3$ -----with both translational and rotational dynamic absorber attached at $x/L=0.3$	32
2.28	Illustration of the experiment set-up of the combined vibration absorbers	32
2.29	Beam with non-linear dynamic vibration absorber	33
2.30	Schematic model	34
2.31	Dynamic model	34
2.32	Optimally tuned and damped system response	34
2.33	Experimental set-up to control flexural waves on a beam structure	34
2.34	Research procedures flowchart	36
3.1	Simplified model	38
4.1	Schematic representation of the experimental set-up of the beam system	45
4.2	Speed control unit front panel	47

4.3	MDAQ-ACC sensor	48
4.4	DEWE 201	48
4.5	Shaker motor weighing using digital scale	49
4.6	Beam illustration	49
4.7	Beam clamping design	54
4.8	Two units of clamping device	54
4.9	Dynamic Vibration Absorber (DVA)	55
4.10	Apparatus set-up	56
4.11	Equipment set-up	57
4.12	Beam division	57
4.13	DVAs in parallel order	59
4.14	Set-up for first condition	59
4.15	Set-up for second condition	60
4.16	Set-up for third condition	60
4.17	Set-up for fourth condition	61
4.18	Beam division	62
4.19	Without DVAs	62
4.20	First condition	63
4.21	Second condition	63
4.22	Third condition	63
4.23	Fourth condition	64
5.1	First mode frequency from experiment results	70
5.2	Second mode frequency experiment results	71
5.3	DVA mass	73
5.4	Free body diagram of beam with tuned mass absorber	74
5.5	Flyer dimension	74
5.6	Dynamic vibration absorber (DVA) (a) Tuned to the 1 st mode (b) Tuned to the 2 nd mode	77
5.7	Displacement (X_m) for beam mass at first mode	81
5.8	Graph for absorber 1 amplitudes	83
5.9	Displacement (X_m) for beam mass at second mode	86
5.10	Graph for absorber 2 amplitudes	88
5.11	(a) First condition set-up; (b) Reduction comparison graph of beam frequencies for first condition	90

5.12	First and second DVA responses graph at first mode frequency	92
5.13	First and second DVA responses graph at second mode frequency	93
5.14	(a) Second condition set-up; (b) Reduction comparison graph of beam frequencies for second condition	95
5.15	First and second DVA responses at first mode frequency	97
5.16	First and second DVA responses at second mode frequency	98
5.17	(a) Third condition set-up; (b) Reduction comparison graph of beam frequencies for third condition	100
5.18	First and second DVA responses at first mod frequency	101
5.19	First and second DVA responses at second mode frequency	102
5.20	(a) Fourth condition set-up; (b) Reduction comparison graph of beam frequencies for fourth condition	104
5.21	First and second DVA responses at first mode frequency	105
5.22	First and second DVA responses at second mode frequency	106
5.23	Close view of combination graph of 4 conditions at first mode (11.23Hz)	108
5.24	Close view of combination graph of 4 conditions at second mode (35.45Hz)	108
5.25	The mode shapes for the beam structure under the boundary conditions; (a) without DVAs, (b) first condition, (c) second condition, (d) third condition and (e) fourth condition for first mode (left) and second mode (right) respectively	112

LIST OF SYMBOLS AND ABBREVIATIONS

D, d	-	Diameter
l	-	length
m	-	mass
r	-	radius
b	-	width
t	-	thickness
k	-	linear spring stiffness
f	-	frequency (Hz)
F, f	-	force
g	-	acceleration constant
ω	-	undamped circular frequency (rad/s)
t	-	time
X, x	-	amplitude displacement
cm	-	centimeter
m	-	meter
∞	-	infinity
Ω	-	natural circular frequency (rad/s)
DVA	-	dynamic vibration absorber
UTHM	-	<i>Universiti Tun Hussein Onn Malaysia</i>

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Steps using DEWESoft 6.5.3	120
B	Beam fundamental mode frequency (first mode)	124
C	Beam fundamental mode frequency (second mode)	132
D	Beam response with DVAs	140



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CHAPTER 1

INTRODUCTION

Until early this century, machines and structures usually had very high mass and damping, because heavy beams, timbers, castings and stonework were used in their construction. Since the vibration excitation sources were often small in magnitude, the dynamic response of these highly damped machines was low. However, with the development of strong lightweight materials, increased knowledge of material properties and structural loading, and improved analysis and design techniques, the mass of machines and structures built to fulfil a particular function has decreased. Furthermore, the efficiency and speed of machinery have increased so that the sources which can create intense vibration problems. The demands made on machinery, structures and dynamic systems are also increasing, therefore the dynamic performance requirements are always rising. There have been very many cases of systems failing or not meeting performance targets because of resonance, fatigue and excessive vibration of one component. Because of the very serious effects which unwanted vibrations can have on dynamic systems, it is essential that vibration analysis be carried out as an inherent part of their design, when necessary modifications can most easily be made to eliminate vibration, or at least it as much as possible. To summarize, present-day machine and structures often contain high-energy sources which create intense vibration excitation problems, and modern construction methods resulted in systems with low mass and low inherent damping. Therefore careful design and analysis is necessary to avoid resonance or undesirable dynamic performance (Beards, 1995).

1.1 Research background

Vibration is mechanical oscillations, produced by regular or irregular period movements of a member or body from its rest position. Vibration can be a source of problem at an engineering level because resulting in damage and loss of control of equipment, and thus reducing the efficiency of operation in machines. Vibration can also cause a discomfort at a low level and at a high level it can risk the person safety (Inman, 2008).

Each vibrating structure has tendency to oscillate with larger amplitude at certain frequencies. These frequencies are known as resonance frequencies or natural frequencies of the structure. At these resonance frequencies, even a small periodic driving force can result in large amplitude vibration. When resonance occurs, the structure will start to vibrate excessively.

The primary method of eliminating vibration is at a source by designing the equipment and ensuring control over the manufacturing tolerances. Others method that can reduce the vibrations that generated by machinery is by modifying the system so that the natural frequencies are not close to the operating speed, to prevent large responses by including damping, install vibration isolating devices between adjacent sub-systems and the other way is include auxiliary mass into the equipment to reduce the response and absorb vibration (Ramamurti, 2008).

In this research, a new control strategy has been tested in order to absorb vibration. This vibration absorbing devices demonstrated as a good vibration absorber when applied on fixed-fixed end beam. In designing a good vibration absorber, the vibrations characteristic need to be studied completely.

Theoretically, every vibration system can be modelled by an equivalent mass-spring vibration system. The excessive vibration can be reduced by mean of a Dynamic Vibration Absorber (DVA). DVA is a device consisting of an auxiliary mass-spring system which tends to 'absorb' the vibration of a system to which it is attached (Rao, 2005; Inman, 2008). A classical DVA consists only a single pair of an auxiliary mass-spring system. This classical DVA only useful for a single degree of freedom system (Bonsel *et al.*, 2004; Wong *et al.*, 2007; Khazanov, 2007), hence limiting its application prospects. Figure 1.1 illustrates the result using dynamic vibration absorber.

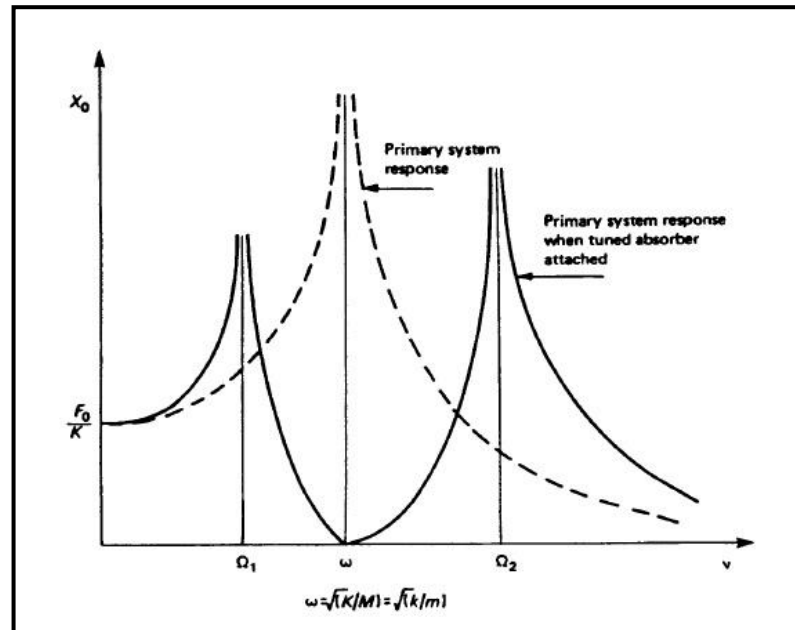


Figure 1.1 : Amplitude- frequency response for system with and without tuned absorber (Beards, 1995)

Figure 1.1 shows the response of a system with and without the use of an absorber. In general, without absorber the primary system has a high peak at certain frequency which indicates the mode of the system. It can be seen from the figure that the absorber, while eliminating vibration at the known impressed frequency of the primary structure, introduces two resonant frequencies Ω_1 and Ω_2 . In practice, the operating frequency must therefore be kept away from the frequencies Ω_1 and Ω_2 . In addition, the argument states that the two invariant points in the frequency response curve of the primary system, its response amplitude is independent of the damping of the absorber system. The stiffness value that results in equal amplitudes at the invariant points is taken to be optimal.

The problem of vibration of a beam is of intrinsic interest because the beam represents the simplest of all engineering structural. The subject of vibrations is of fundamental importance in engineering and technology. In this research project, an analysis of a DVA for a multi degree of freedom system i.e. beams structures is going to be investigated. This special DVA can be used to control the vibration level of a building built in earthquake prone area, to control the vibration level of a bridge exposed to high speed or turbulence wind and to control airplanes wing flutter.

1.2 Problem statement

Excessive vibration in engineering systems are generally undesirable and therefore avoided for the sake of safety and comfort. Vibration has been known as the factor of disturbance, discomfort, damage and destruction. It could also lead to excessive deflections and failure on the machines and structures. Exposure to vibration for a long period also can be harmful where it causes disease and muscular-skeletal pain. Thus, vibration needs to be eliminated with the effective ways to prevent all the bad effects. It is possible to reduce untoward amplitudes by attaching to the main vibrating system an auxiliary oscillating system. Therefore, this study was undertaken to reduce the risk stated by producing a new design of dynamic vibration absorber (DVA) attached to a structure called fixed-fixed end beam.

Most of researches focus on the applications of absorbers in the system under harmonic excitations with a single frequency. However, many systems in real applications are excited more than two frequencies. In addition, only few research done in study the characteristics of DVA involving two DVAs in a system. Due to these circumstances, a research theoretically and experimentally using DVA which tuned up to second mode need to be conducted.

1.3 Research aim

This research aims to study on absorber system and its tuning for a fixed-fixed end beam.

1.4 Objective (s) of the research

The main objective of this research is to study the vibration characteristics of a new designed dynamic vibration absorber attached on fixed-fixed beam subjected to force vibration frequency loading.

Based on the research gaps identified in literature survey, this study embarks on the following objectives;

- i) To develop a theoretical mathematical model for the development of DVA for two degree of freedom system based on classical vibration absorber equation.
- ii) To verify the theoretical model of the DVA by experimental works.
- iii) To determine the vibration characteristics of a vibration system attached with the developed DVA analytically and experimentally.

1.5 Scopes

The research is focused on fixed-fixed end beam subjected to two frequency loading.

This research is limited according to the scopes below:

- (a) Theoretical analysis to tune the DVA to the beam.
 - The analytical derivation only presented for the first two degree of freedoms.
- (b) Calculation to determine the beam dimension so its do not exceed the frequencies produced by exciter motor.
 - The speed control of the motor is up to 3000 rev/min.
- (c) Design and fabrication the beam holder
 - The beam rig designing process are restrained to the experimental lab equipment at UTHM vibration laboratory.
 - Fabricated in 2 pieces so that the beam attachment could be fixed at both sides.
- (d) Determine the vibration levels of the beam by running a force vibration test so that a comparison before and after using DVA could be obtained.
 - This initial test run conduct until reach the motor's maximum speed.
- (e) Calculation work to determine the appropriate design of DVA to get the optimum tuned mass absorber for the beam.
 - The optimum parameters such as stiffness, mass and natural frequency.
 - Calculate the l , length for the both sides absorber flyers.
- (f) DVAs fabrication
 - Most of the absorber parts are made of aluminium material.

(g) Experimental work to measure the beam amplitude after mounting DVA.

- Two DVAs attached to the structure and vibrated using shaker.
- Conducted at vibration laboratory, UTHM.
- Check the optimum tuned mass absorber for fixed-fixed beam.

1.6 Expected outcomes

The results from this research is expected that the proposed dynamic vibration absorber will absorb the structure vibration levels at constant frequency range. Subsequently, it will achieve the objective where the vibration characteristic of a dynamic vibration absorber attached on a fixed-fixed beam is studied. Figure 1.2 describes the expected amplitude-frequency response obtained before and after using two DVAs. Refer to the graph, the important thing is that after using the absorbers the structure primary amplitudes expected to be lowered at certain frequency.

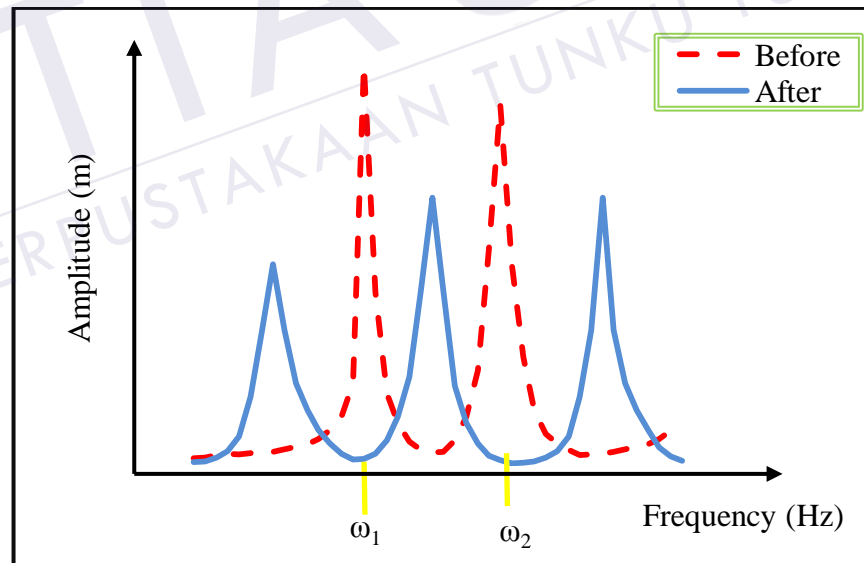


Figure 1.2 : Expected amplitude-frequency response using DVA

1.7 Significant of research

In engineering history, excessive vibration has been a common problem in causing the fatigue life of structures shorter and the performance of machines reduces. The intensity of vibration sources around us is increasing and tolerances on allowable vibration levels are becoming more and more stringent. From this phenomena, we know that vibration affects the machines and structures life span. Due to this, it is necessary to come out for a solution by solving from its root.

Vibration also can be harmful and therefore should be avoided. The most effective way to reduce unwanted vibration is to suppress the source of vibration. Above this condition, this research was carried out to understand the vibration characteristic in order to design a dynamic vibration absorber due to the needs of vibration protection itself. As a result, it gave an idea on how to produce an effective absorber. The knowledge gained from this research can be used to minimize the vibration amplitude of a structures and machines, increasing their life-span simultaneously. A complete understanding of vibration is needed involves in the analysis and design of a vibration absorber devices so this are the importance why this study should be conducted.

This research also has its own novelty in theories and knowledge whereas the finding of this research is instrumental in terms of identifying key of theoretical and mathematical model in development of DVA for multi degree of freedom systems. The other benefit comes from this research in specific or potential application aspect is it could control vibration in building or bridge structure and airplane wing flutter control.

CHAPTER 2

LITERATURE STUDY

This chapter gives insight into vibration theory, vibration control, beam, dynamic vibration absorber (DVA) and previous research done on dynamic vibration absorber.

2.1 Concept of vibration

Variations in physical phenomena that take place more or less regularly and repeated themselves in respect to time are described as oscillations. In other words, any motion that repeats itself after an interval of time is called vibration or oscillation. The theory of vibration deals with the study of oscillatory motion of bodies and the associated forces. The oscillatory motion shown in Figure 2.1 below is called harmonic motion and is denoted as

$$x(t) = X \cos \omega t \quad (2.1)$$

The theory of vibration deals with the study of oscillatory motions of bodies and the forces associated with them (Rao, 2005). Vibration also is the study of the repetitive motion of objects relative to a stationary frame of reference or nominal position (usually equilibrium).

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